AEROSOL FORCINGS

WHY IT IS ESSENTIAL THAT THEY BE DETERMINED, AND SOME IDEAS ON HOW

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Joint Meeting

Aerosol Working Group
Cloud Modeling Working Group

Boulder, Colorado
September 29 – October 2, 2009

OBJECTIVES OF CLIMATE CHANGE RESEARCH IN DOE

Develop confident ability to project the climate change that would result from putative future changes in atmospheric composition.

Develop ability to answer "***what if?***" questions on future climate change useful for planning the Nation's and the World's energy future.

This is a ***quantitative*** requirement. ***A factor of 2 looms large!***

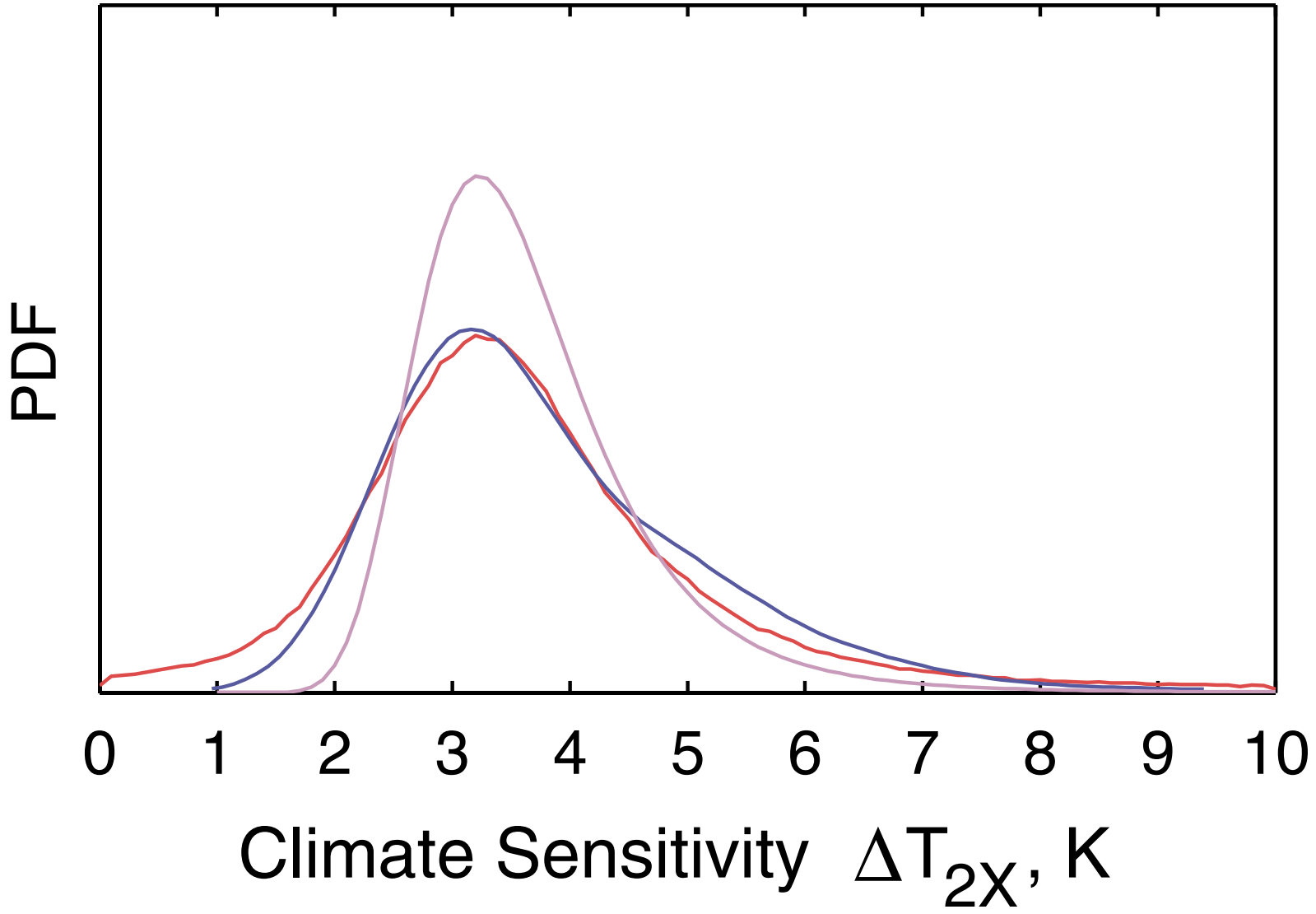
Bring the elements of ARM and ASP to focus on the major issues limiting this capability:

Climate forcing

Climate sensitivity

CLIMATE SENSITVITY

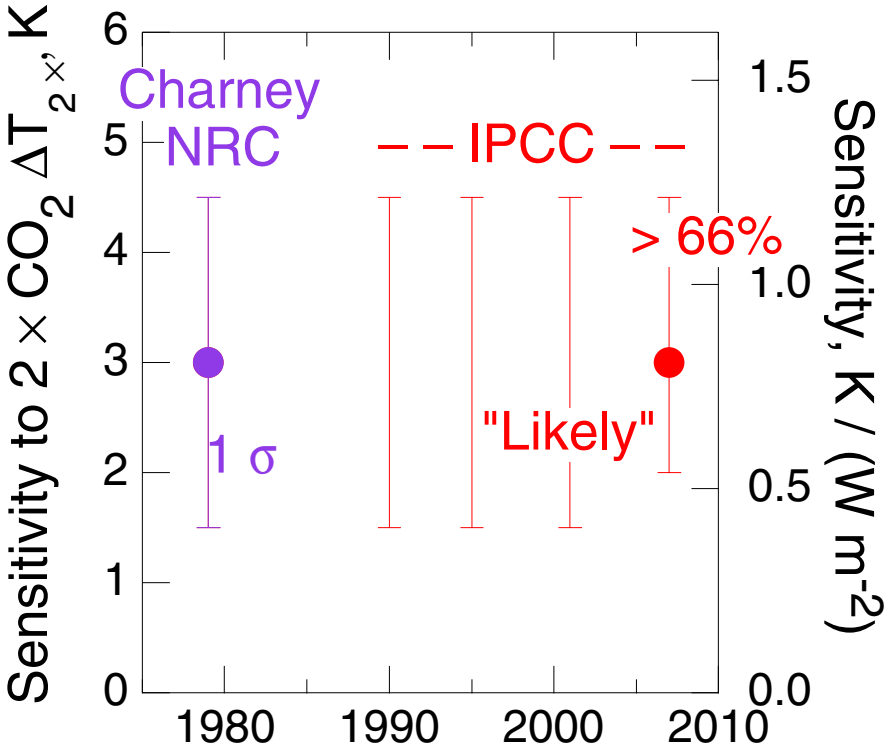
Probability Distribution Function Estimates from IPCC AR4 (2007)

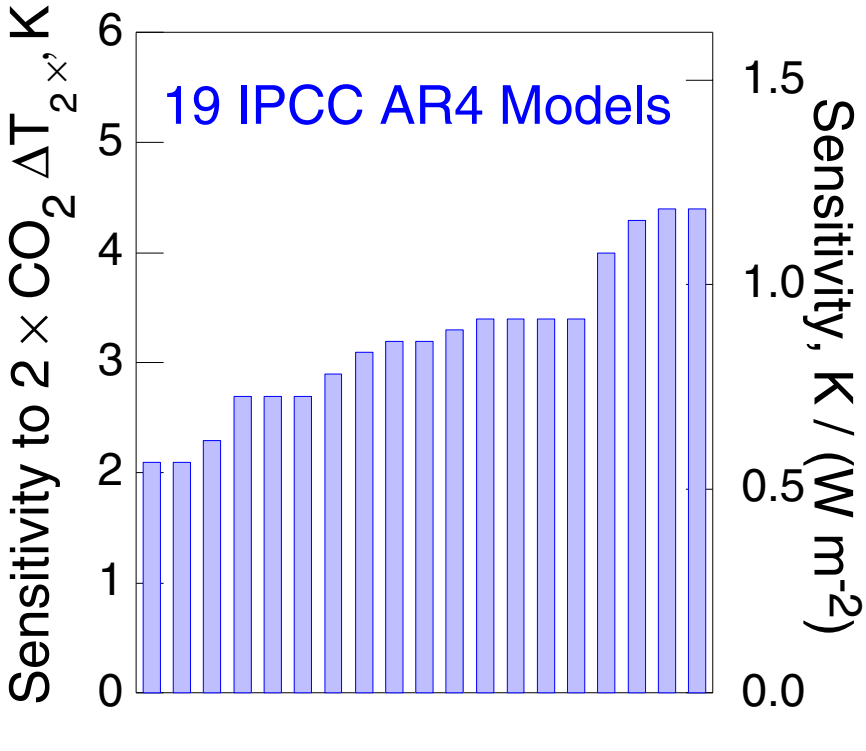


Current estimates are not well constrained.

ESTIMATES OF EARTH'S CLIMATE SENSITIVITY AND ASSOCIATED UNCERTAINTY

Major national and international assessments and current climate models



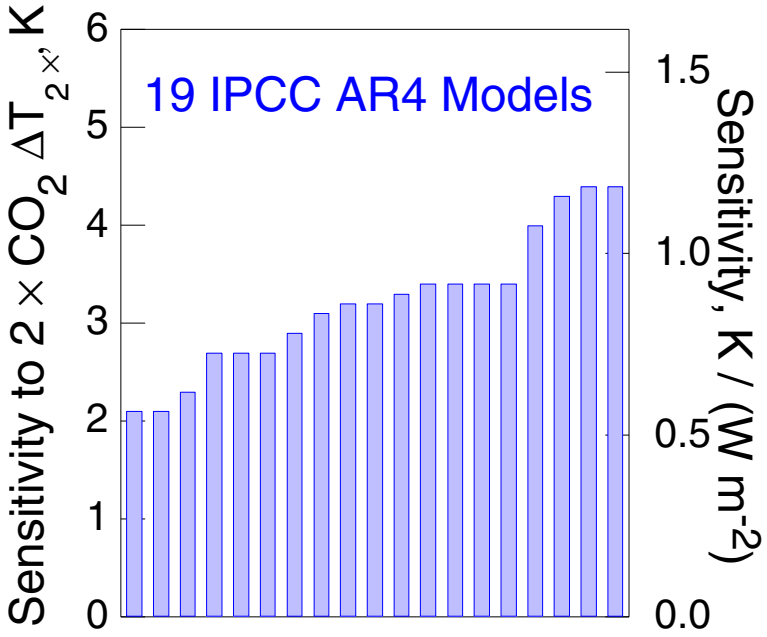


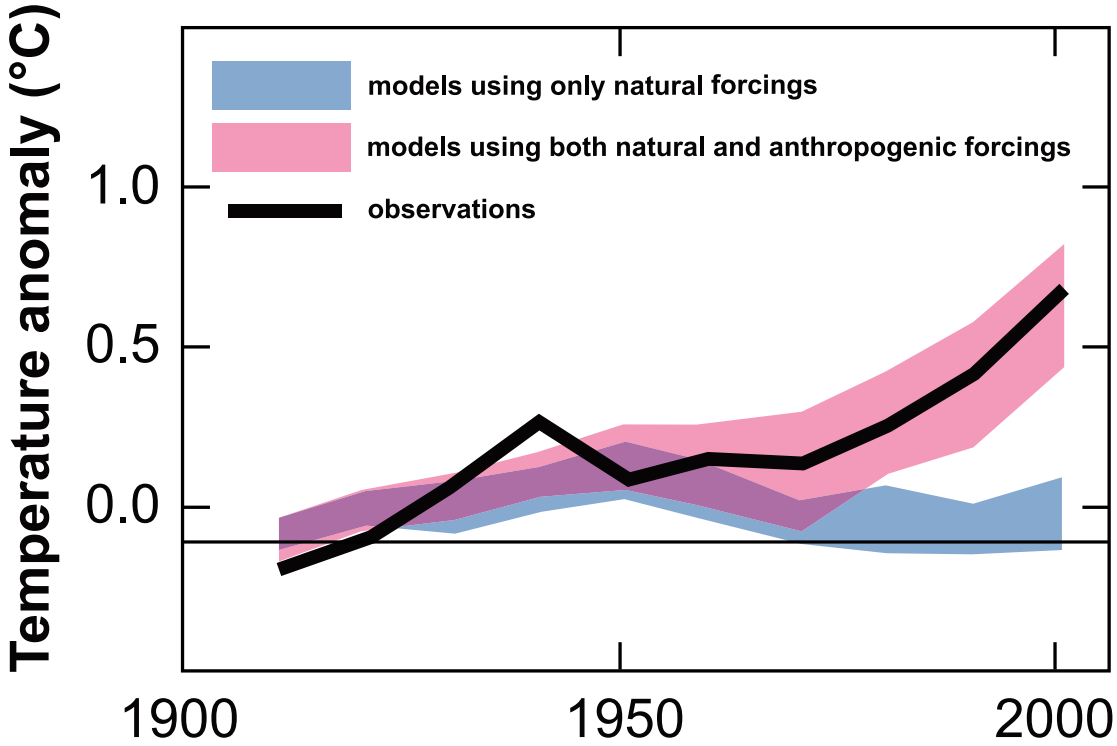
Current estimates of Earth's climate sensitivity are centered about a CO_2 doubling temperature $\Delta T_{2\times} = 3$ K, but with substantial uncertainty.

Range of sensitivities of current models roughly coincides with IPCC "likely" range.

TOO ROSY A PICTURE?

Ensemble of 58 model runs with 14 global climate models





- Simulations that incorporate anthropogenic forcings, including increasing greenhouse gas concentrations and the effects of aerosols, and that also incorporate natural external forcings provide a ***consistent explanation of the observed temperature record***.
- These simulations used models with ***different climate sensitivities, rates of ocean heat uptake and magnitudes and types of forcings***.

IPCC AR4, 2007

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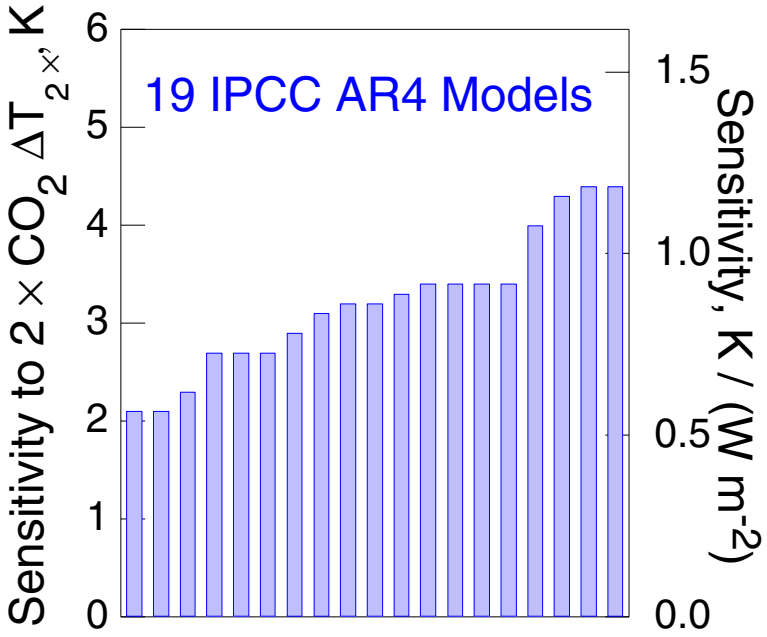

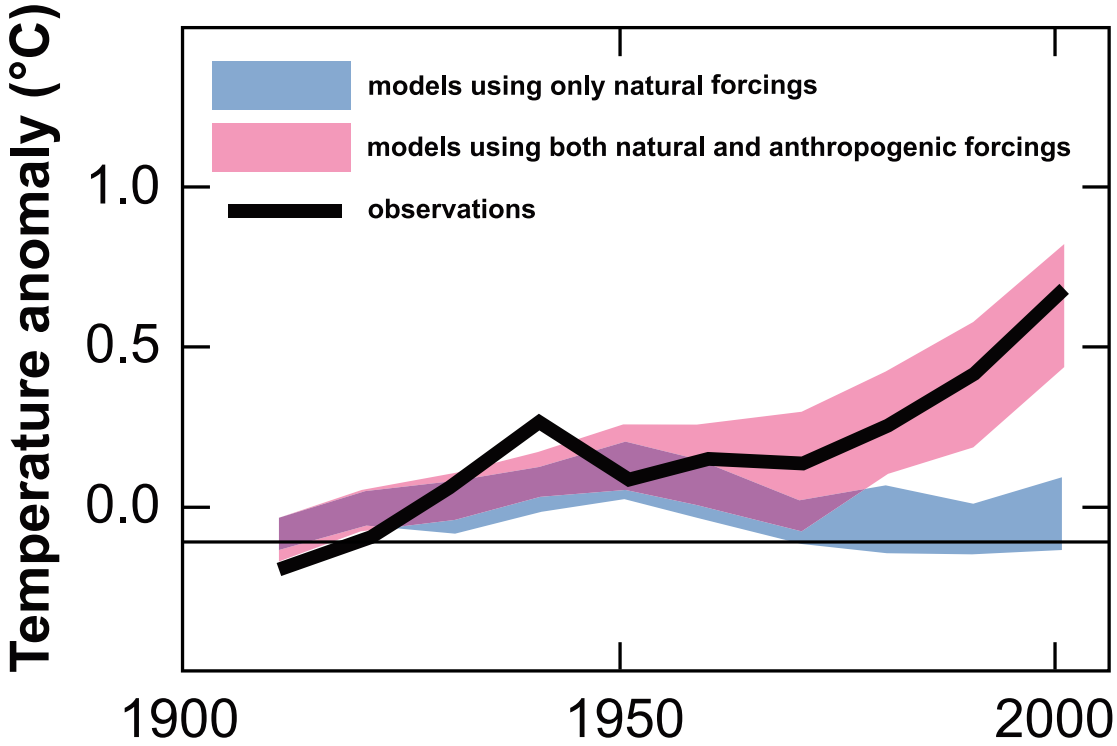

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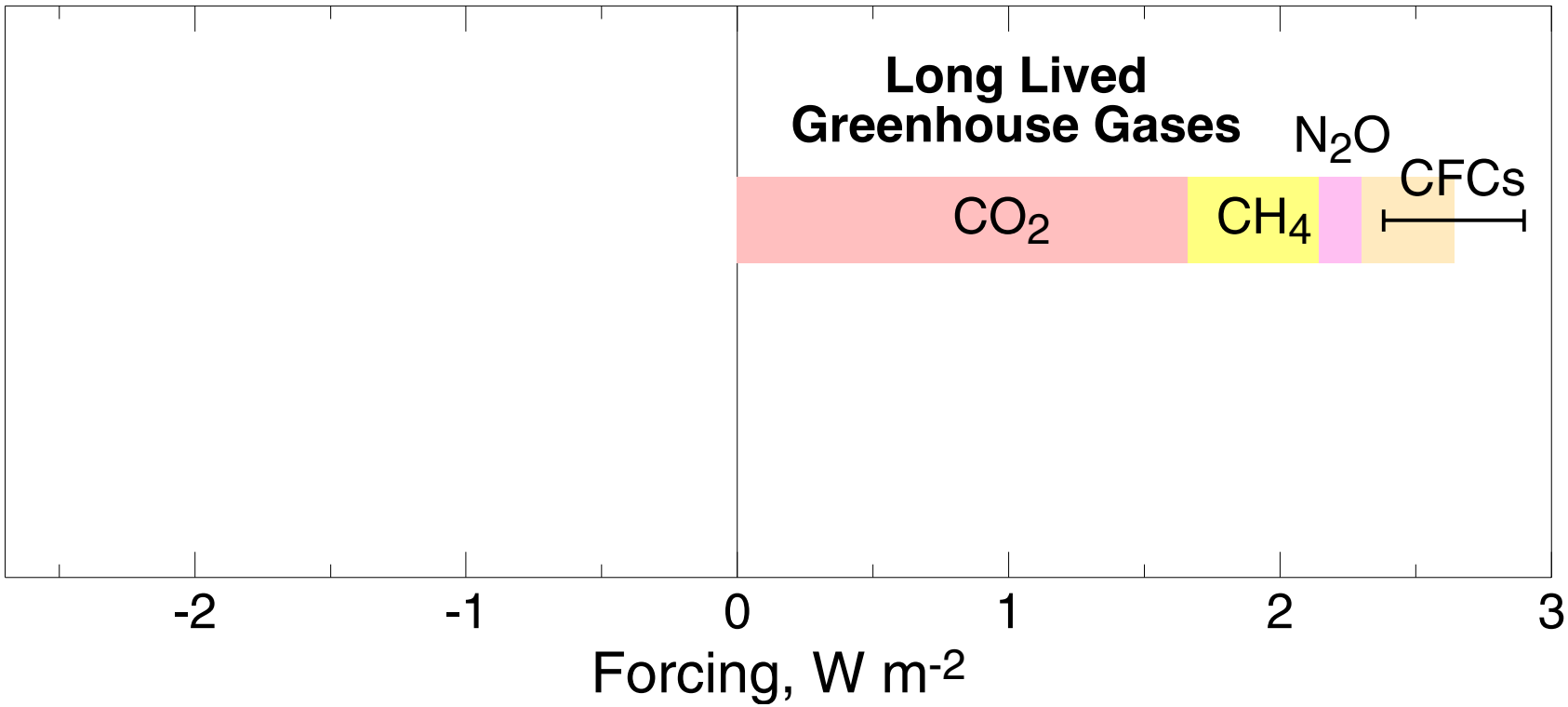
IPCC AR4, 2007

How can this be?

CLIMATE FORCINGS OVER THE INDUSTRIAL PERIOD

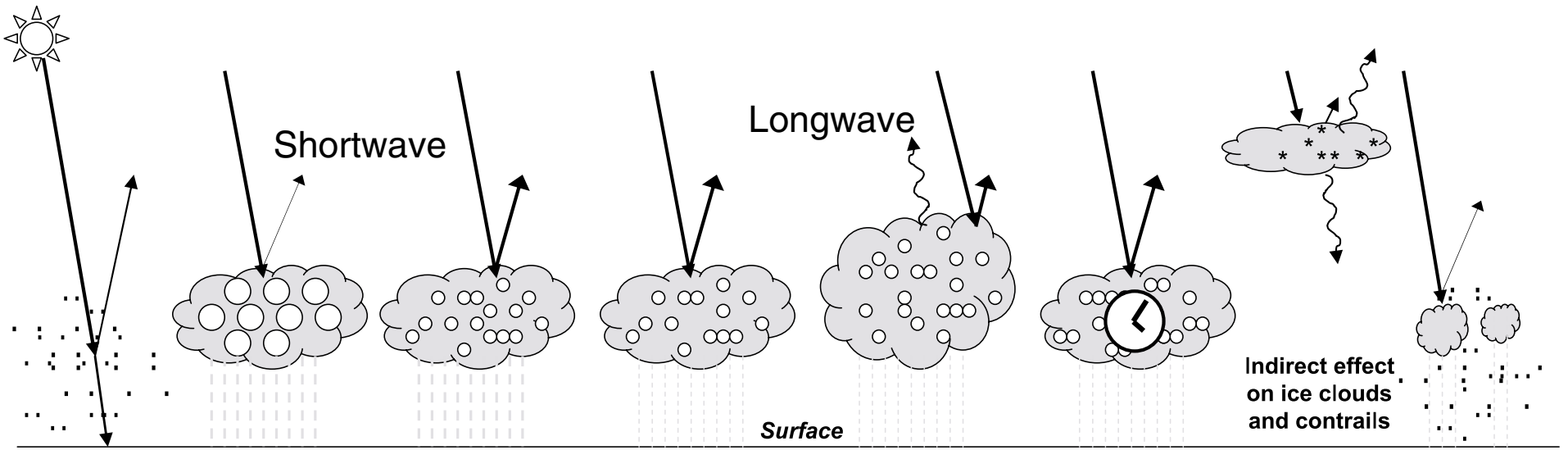
Extracted from IPCC AR4 (2007)



Greenhouse gas forcing is considered accurately known.

Gases are uniformly distributed; radiation transfer is well understood.

AEROSOL EFFECTS ON CLOUDS AND RADIATION



IPCC AR4 (2007) after Boucher and Haywood, 2000

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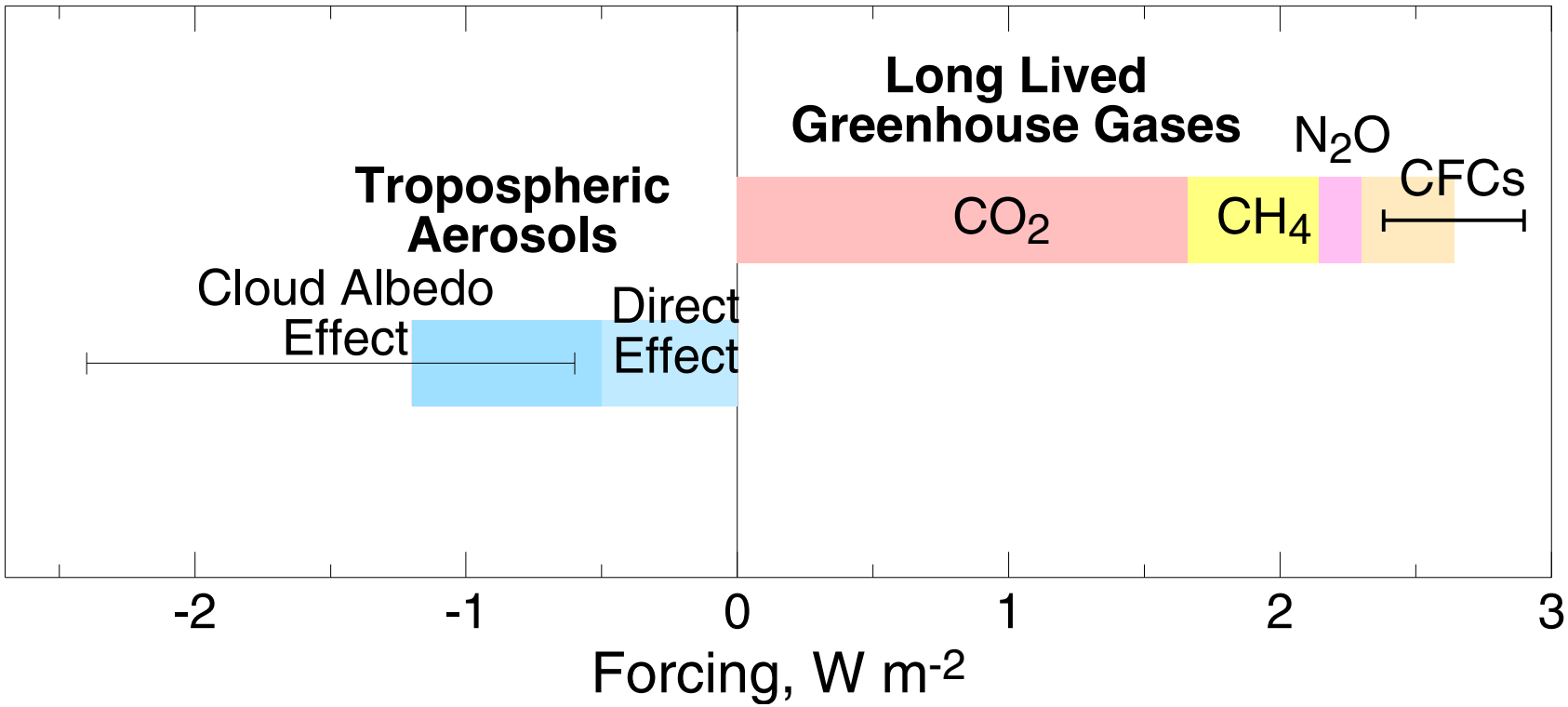

Negative aerosol forcing substantially offsets GHG forcing.

Aerosol forcing is highly uncertain.

CLIMATE FORCINGS OVER THE INDUSTRIAL PERIOD

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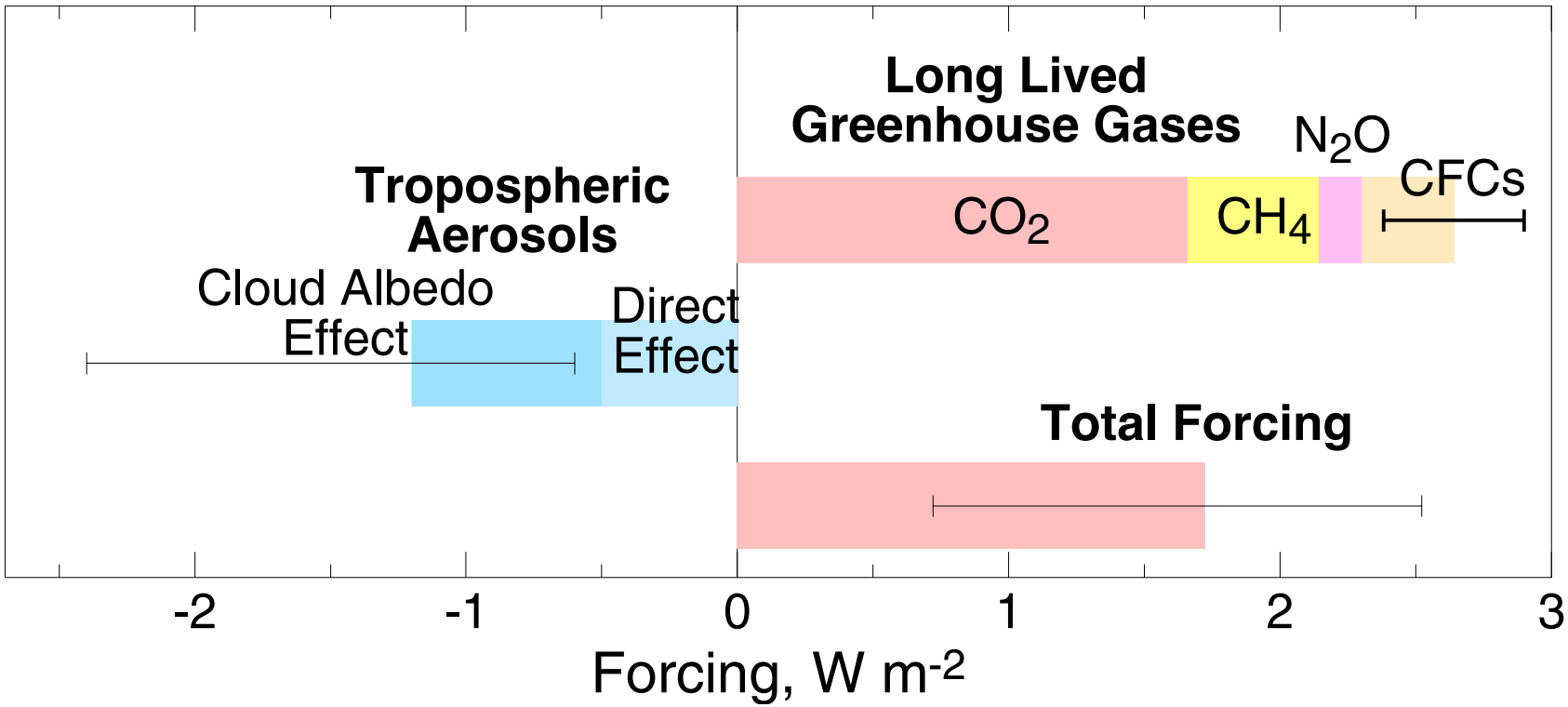


Total forcing includes other anthropogenic and natural (solar) forcings.

Forcing by tropospheric ozone, ~0.35 W m^{-2}, is the greatest of these.

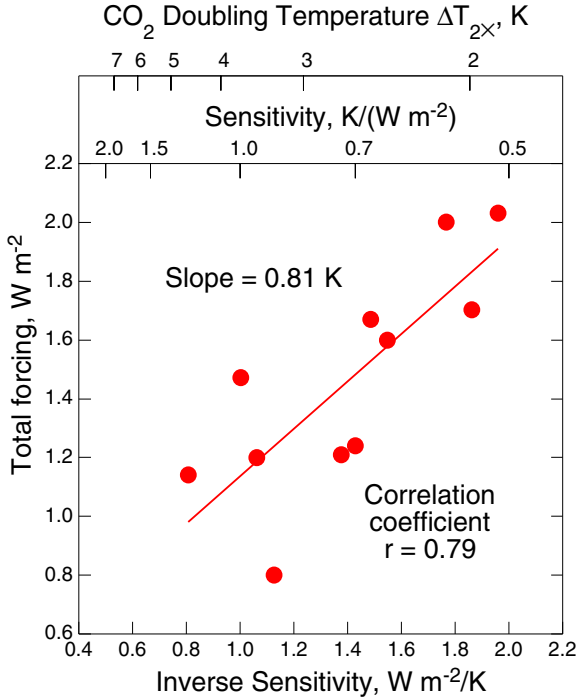
Uncertainty in aerosol forcing dominates uncertainty in total forcing.

CORRELATION OF AEROSOL FORCING, TOTAL FORCING, AND SENSITIVITY IN CLIMATE MODELS

Nine coupled ocean-atmosphere models; two energy balance models

$$S = \Delta T / F$$

$$F = \Delta T \, S^{-1}$$



Modified from Kiehl, GRL, 2007

Total forcing is linearly correlated with inverse sensitivities of the models.

Climate models with lower sensitivity (higher inverse sensitivity) employed a greater total forcing.

Slope (0.8 K) is approximately equal to observed temperature change. Models accurately reproduce known temperature change.

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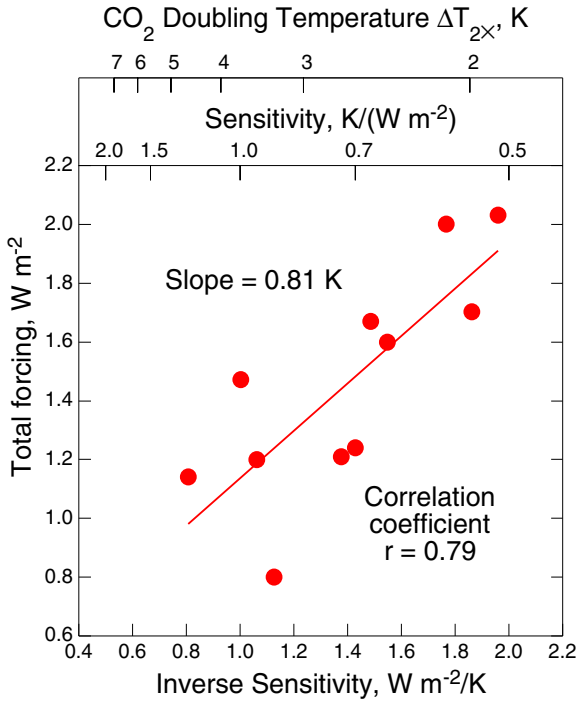

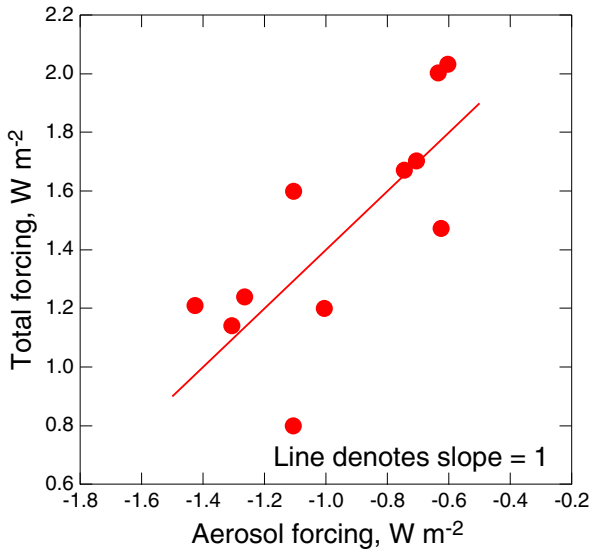

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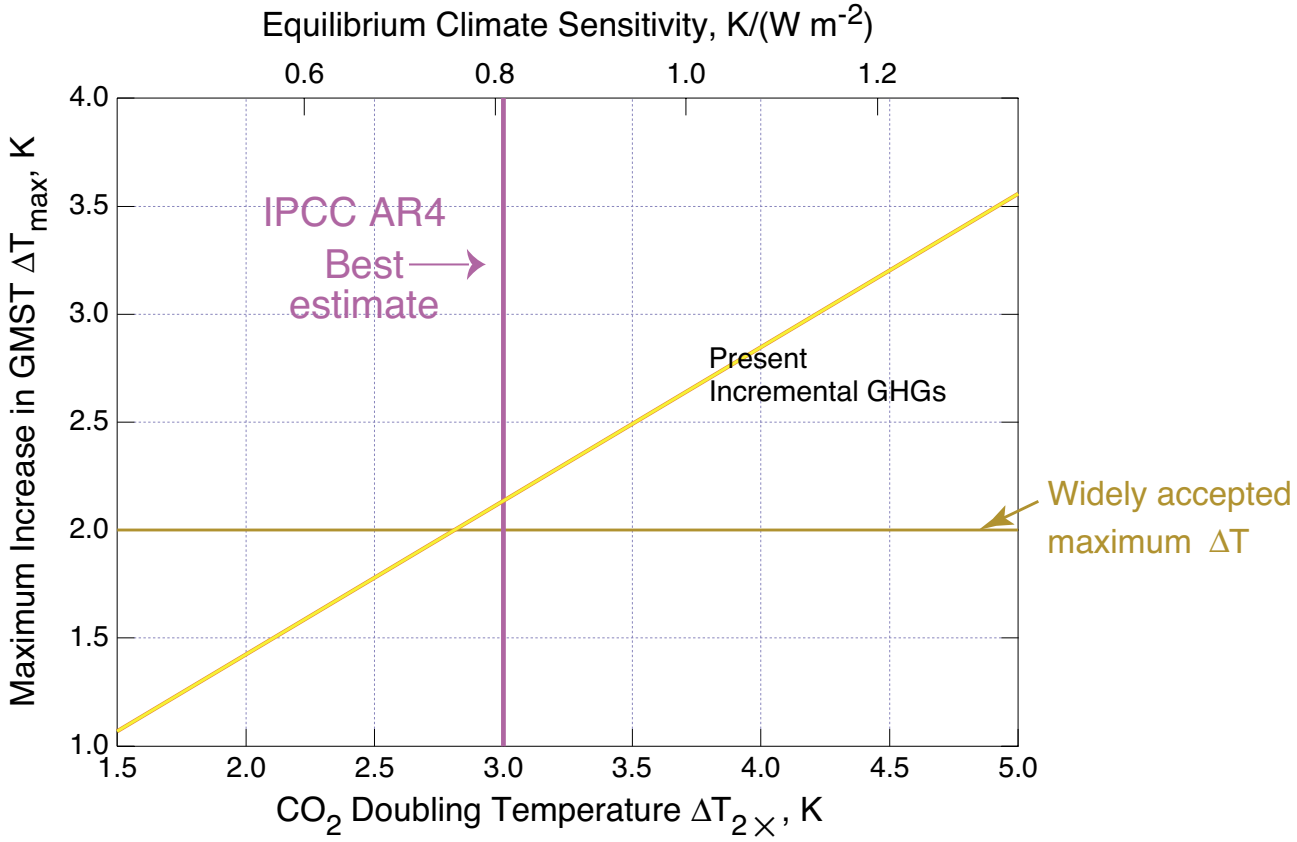
Greater total forcing is due to smaller (less negative) aerosol forcing.

ALLOWABLE FUTURE CO_2 EMISSIONS

Dependence on climate sensitivity and acceptable increase in temperature relative to preindustrial



For $\Delta T_{\max} = 2$ K,

If sensitivity $\Delta T_{2\times}$ is 3 K, ***no further emissions!***

ALLOWABLE FUTURE CO_2 EMISSIONS

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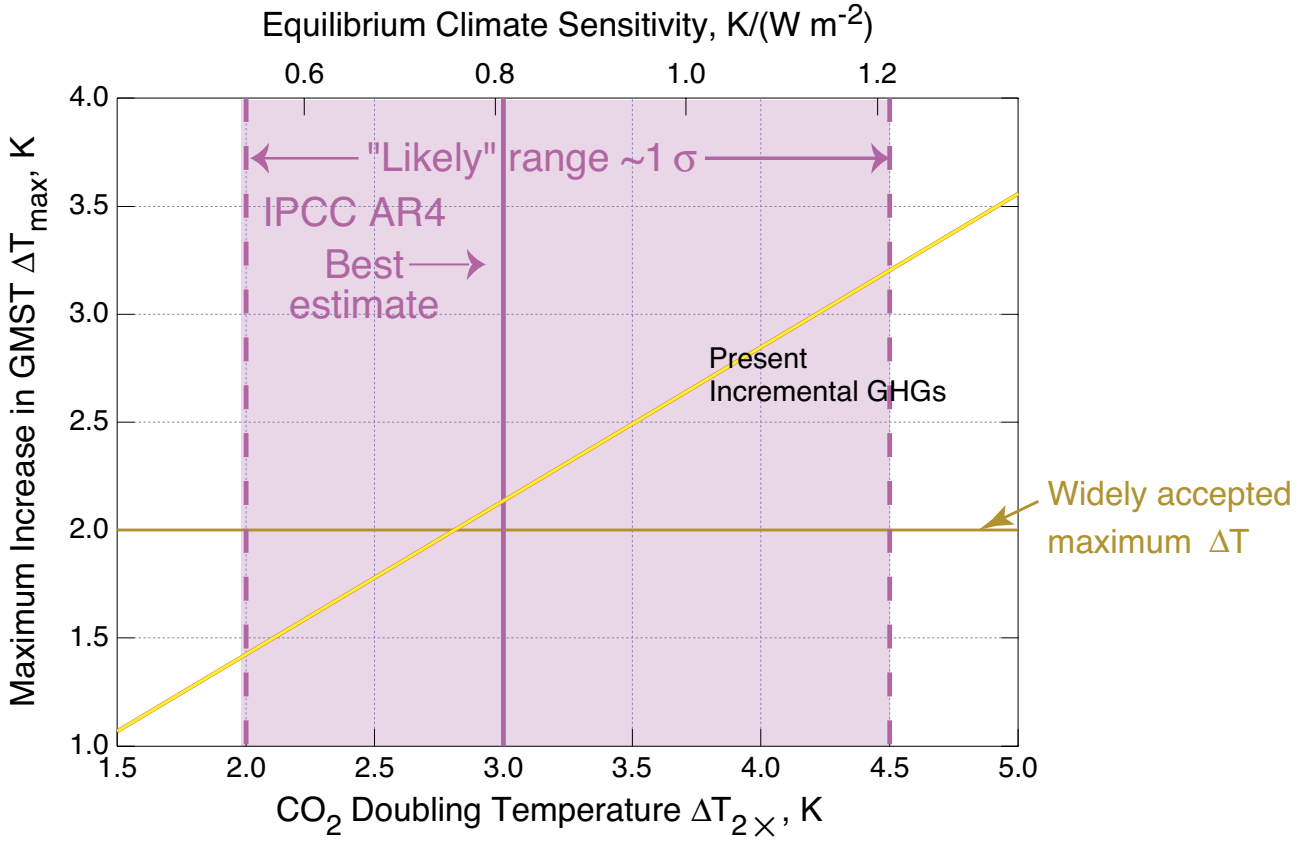

For $\Delta T_{\max} = 2$ K,

Allowability of future emissions depends on climate sensitivity.

ALLOWABLE FUTURE CO_2 EMISSIONS

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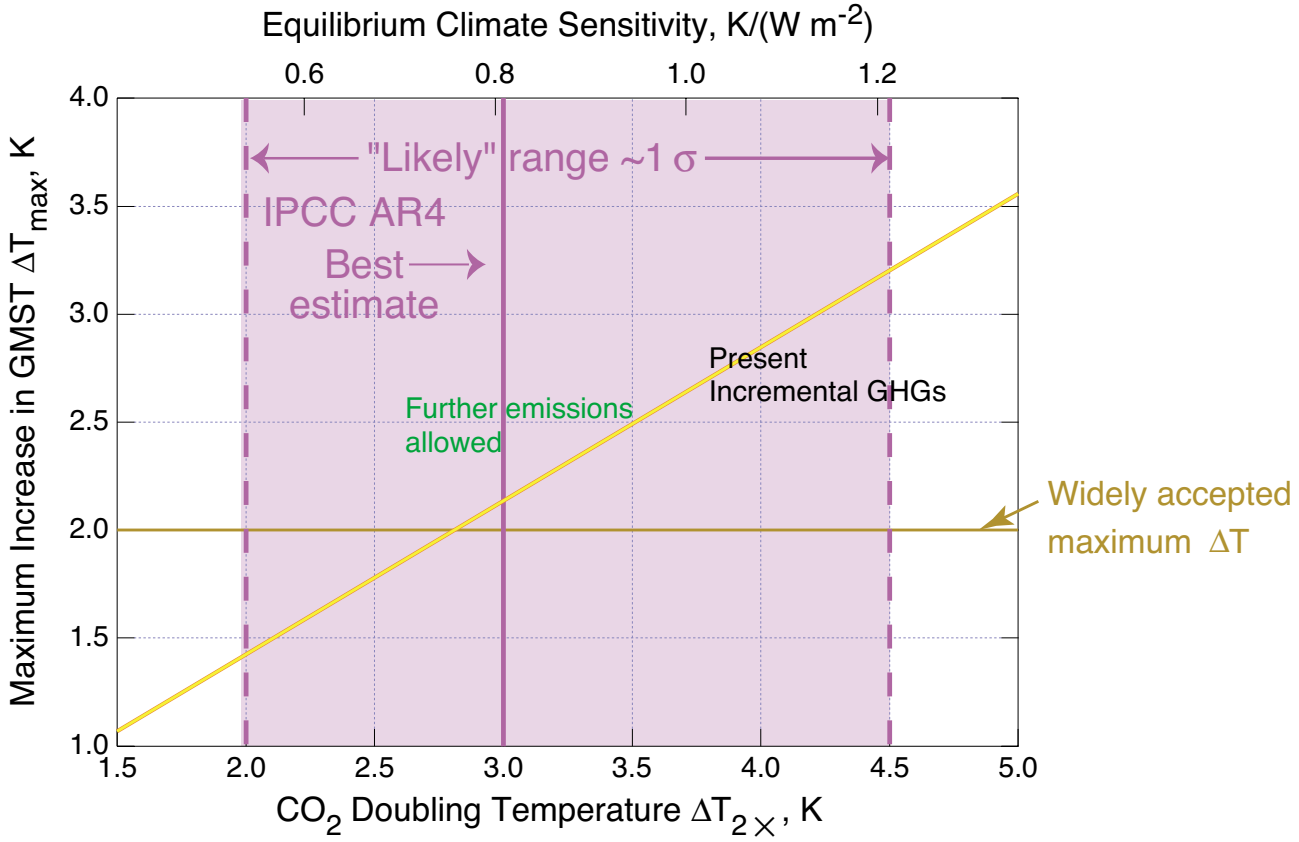

If $\Delta T_{\max} > 2.1$ K and/or sensitivity $\Delta T_{2\times} < 3$ K, further emissions are allowed without exceeding $\Delta T_{\max}$.

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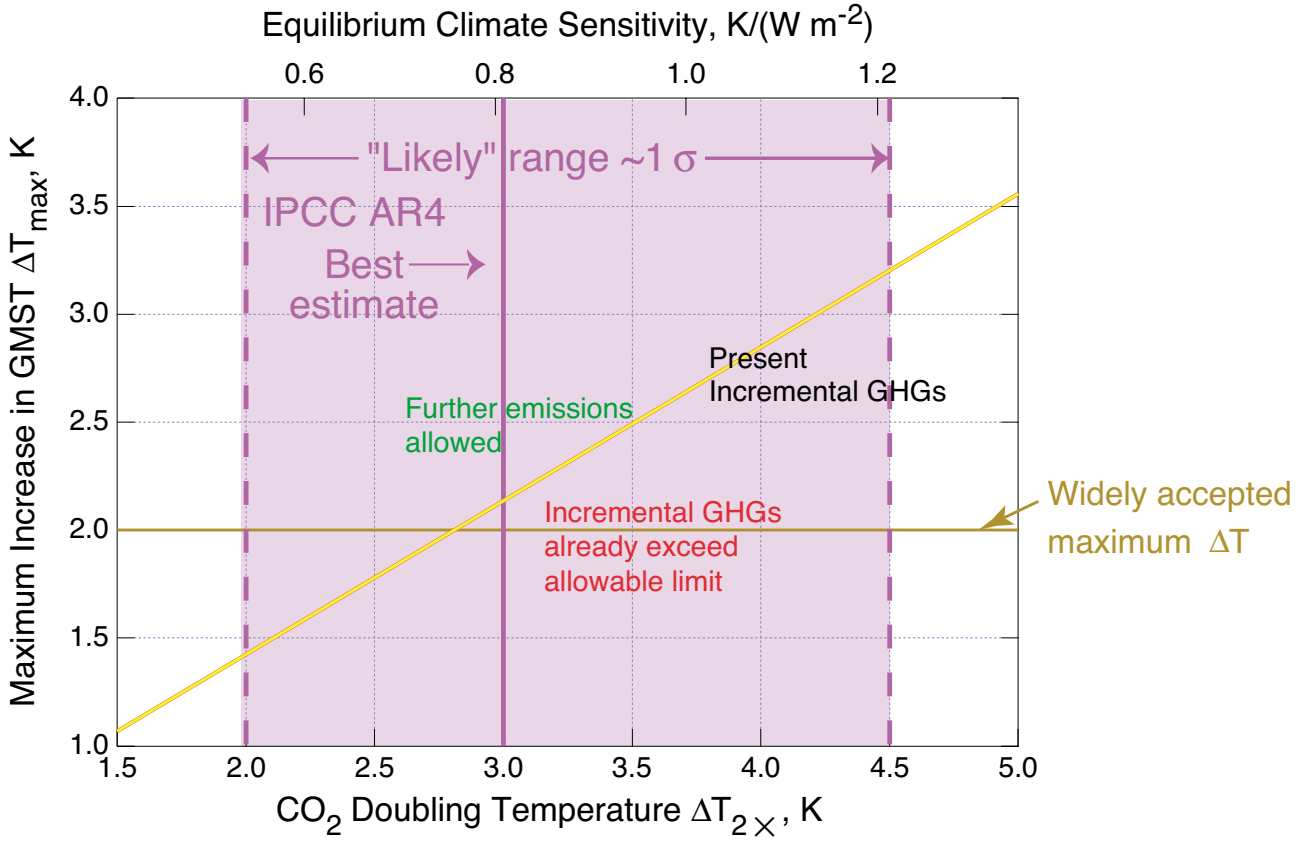
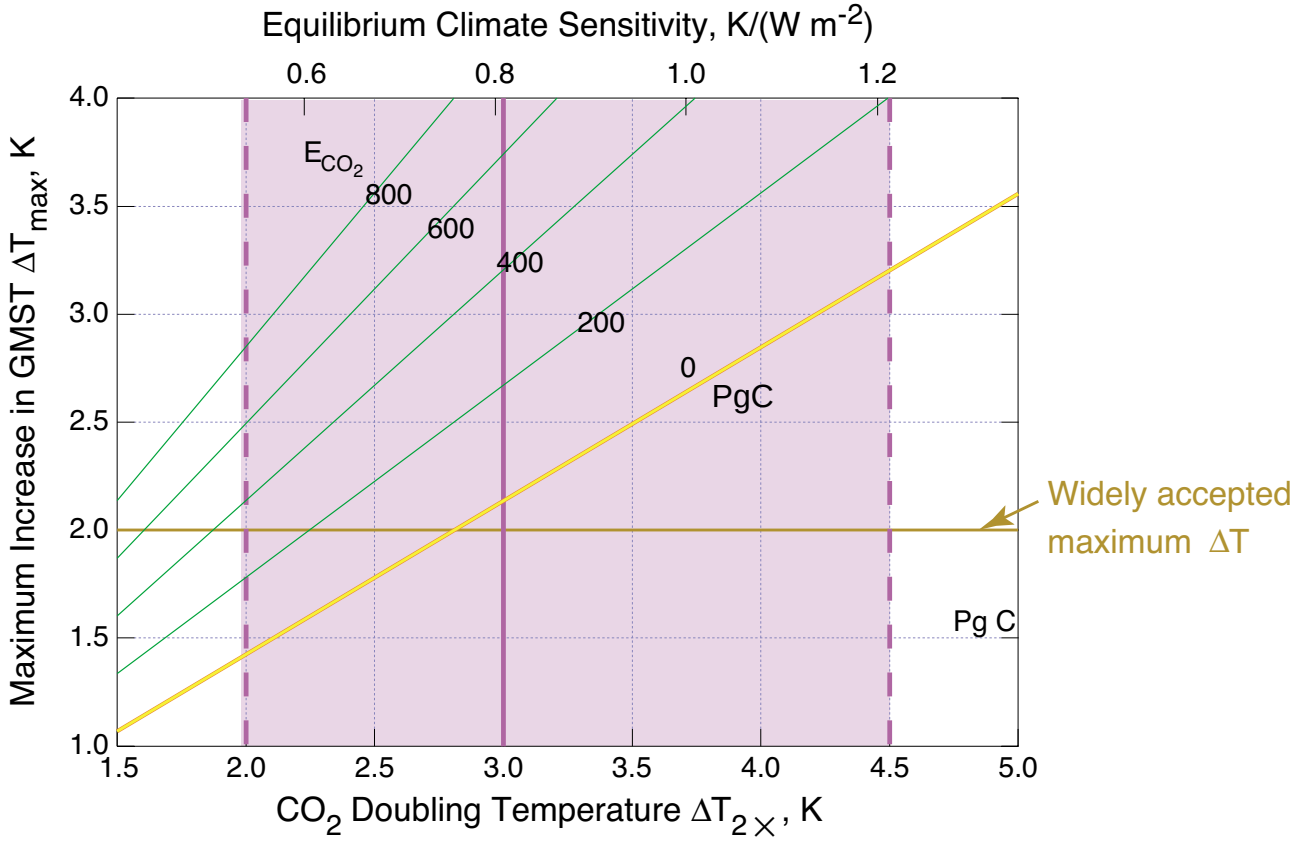


If $\Delta T_{\max} > 2.1$ K and/or sensitivity $\Delta T_{2\times} < 3$ K, further emissions are allowed without exceeding $\Delta T_{\max}$.

If $\Delta T_{\max} < 2.1$ K and/or sensitivity $\Delta T_{2\times} > 3$ K, committed temperature increase already exceeds $\Delta T_{\max}$.

ALLOWABLE FUTURE CO_2 EMISSIONS

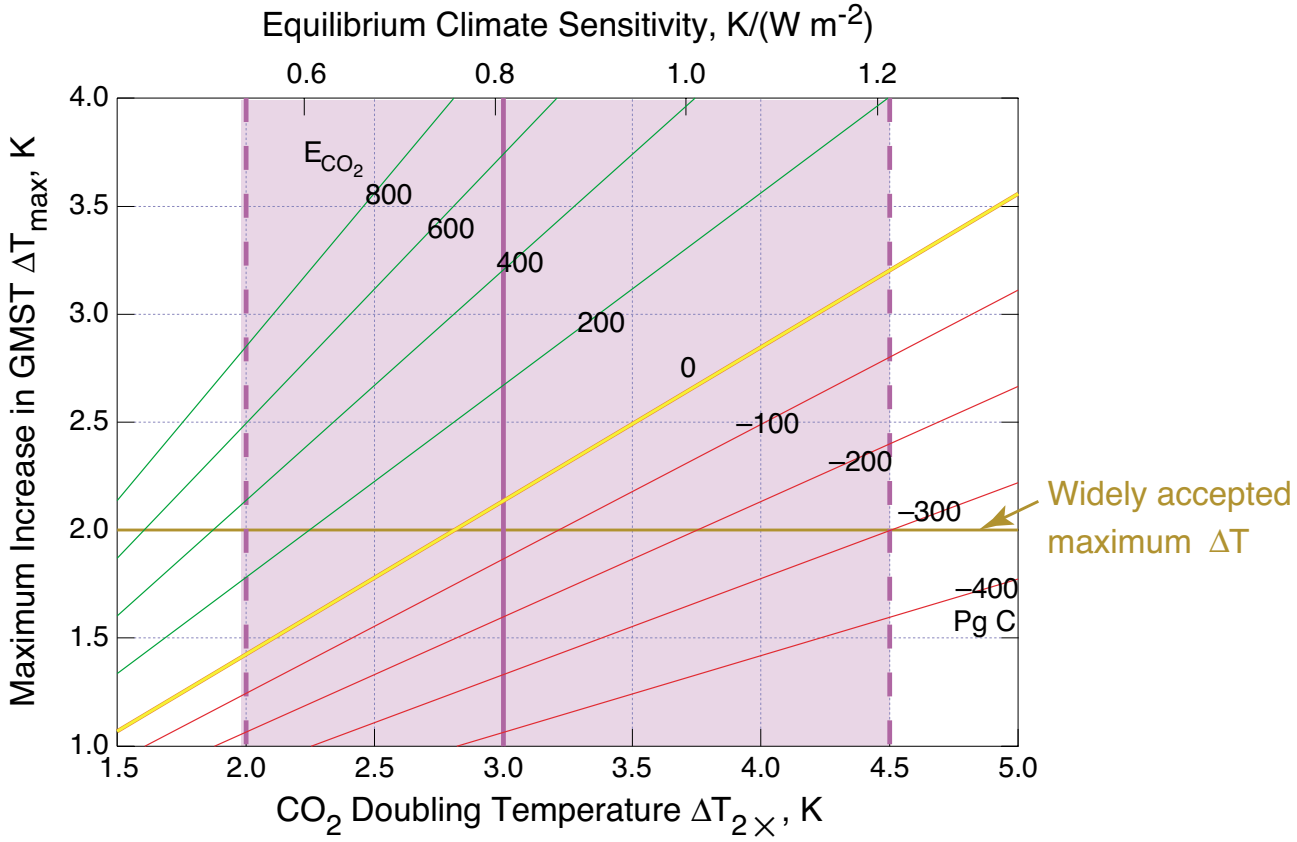
Dependence on climate sensitivity and acceptable increase in temperature relative to preindustrial



Allowable future emissions depend on climate sensitivity and $\Delta T_{\max}$.

ALLOWABLE FUTURE CO_2 EMISSIONS

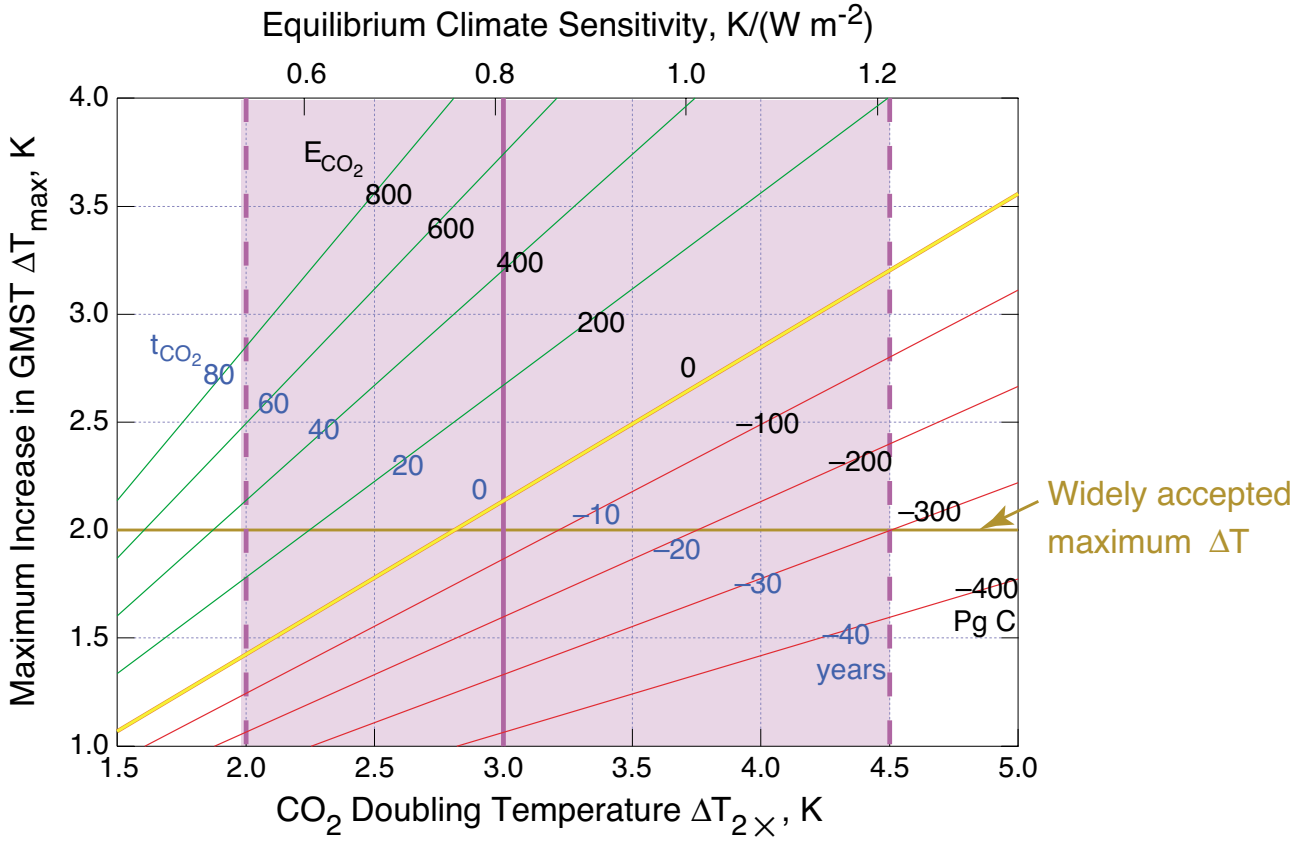
Dependence on climate sensitivity and acceptable increase in temperature relative to preindustrial



Allowable future emissions ***or amount by which present GHGs exceed the allowable threshold*** depend on climate sensitivity and $\Delta T_{\max}$.

ALLOWABLE FUTURE CO_2 EMISSIONS

Dependence on climate sensitivity and acceptable increase in temperature relative to preindustrial



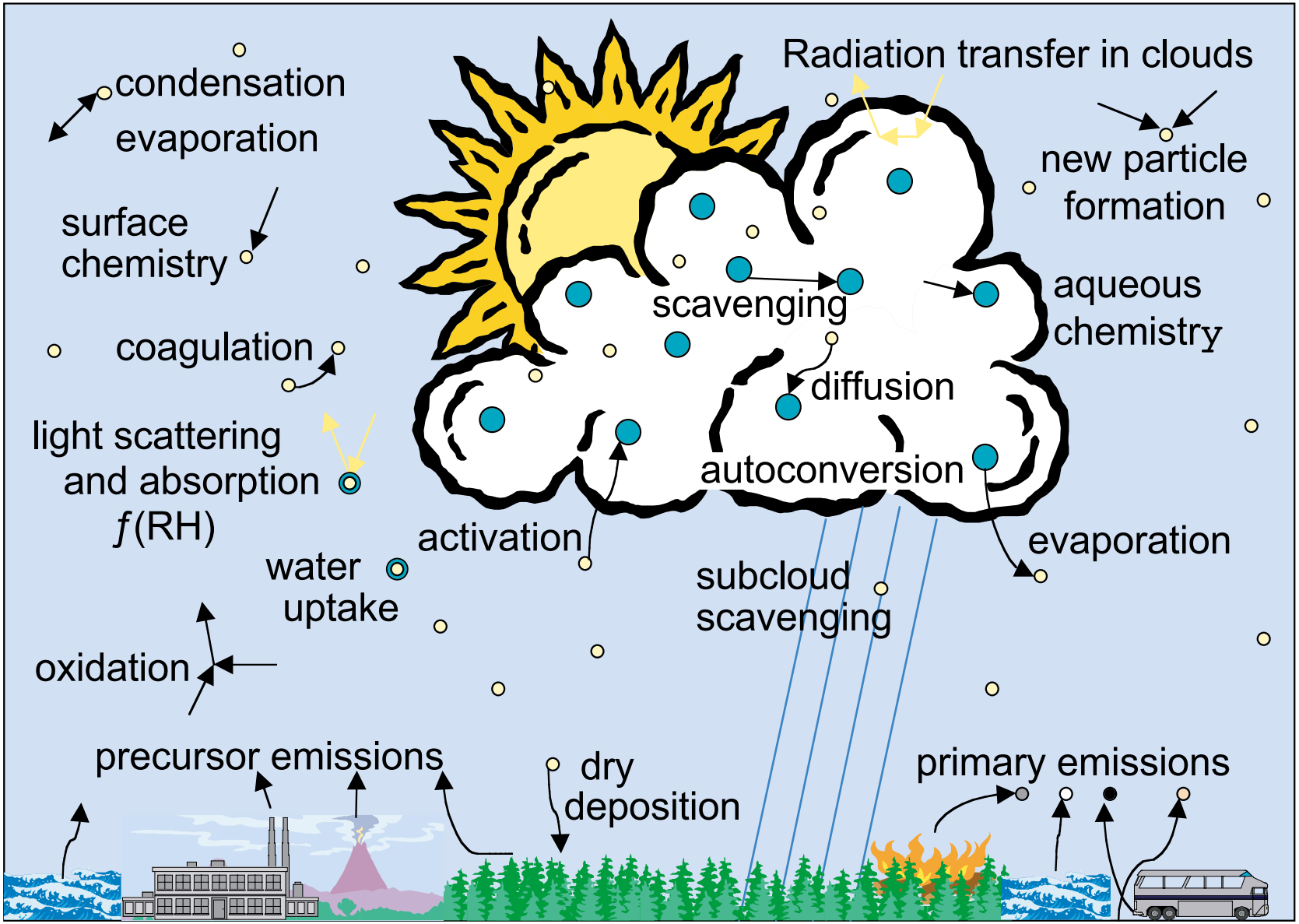
For $\Delta T_{max} = 2$ K . . .

If sensitivity $\Delta T_{2\times}$ is 3 K, ***no more emissions***.

If sensitivity $\Delta T_{2\times}$ is 2 K, ~ ***30 more years of emissions at present rate***.

If sensitivity $\Delta T_{2\times}$ is 4.5 K, ***threshold is exceeded by ~30 years***.

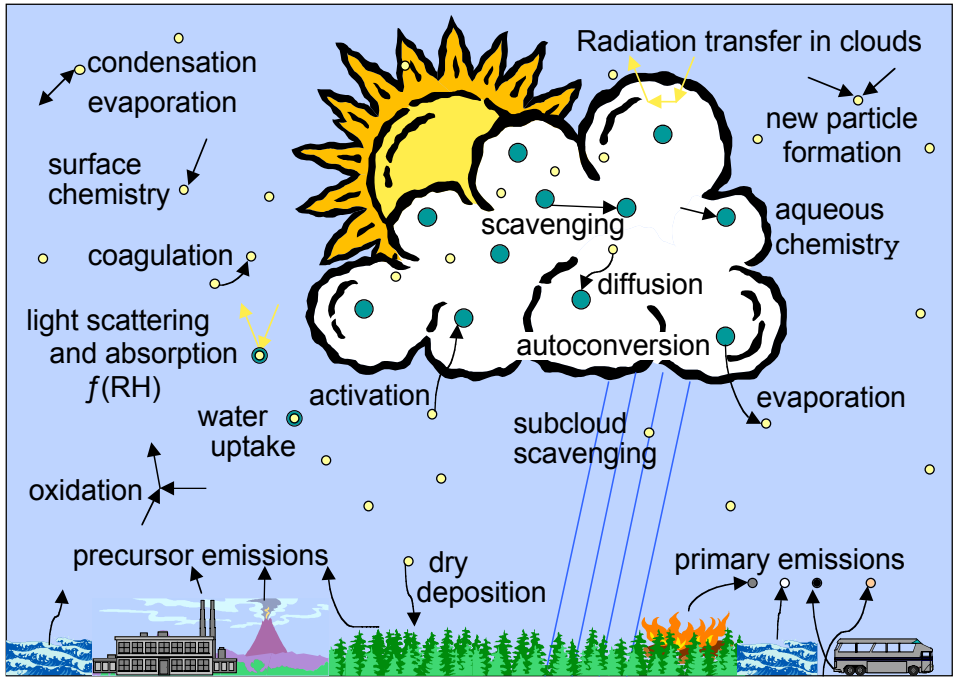
AEROSOL PROCESSES THAT MUST BE UNDERSTOOD AND REPRESENTED IN MODELS

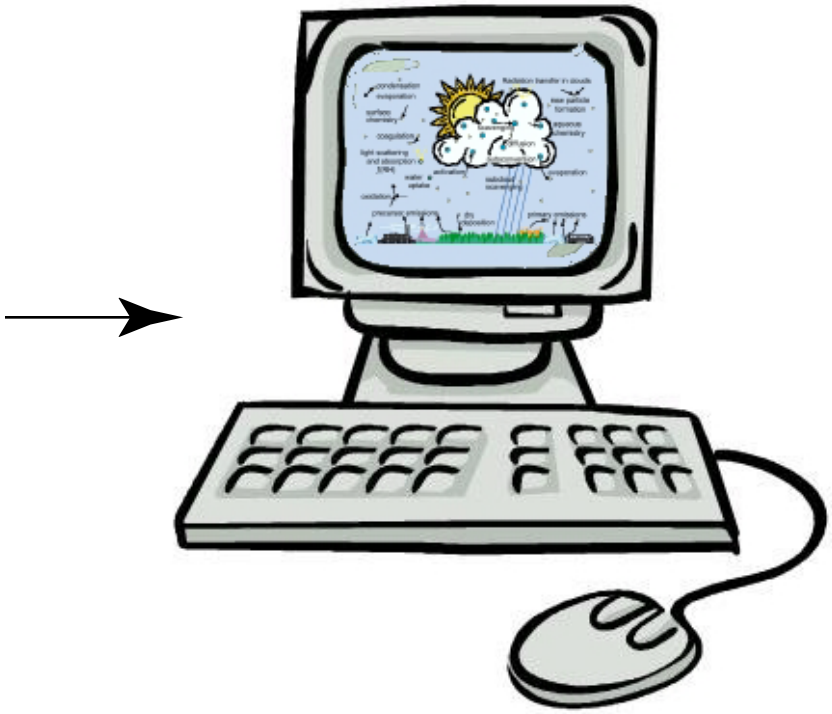


Modified from Ghan and Schwartz, Bull. Amer. Meterol. Soc., 2007

APPROACH TO DETERMINE AEROSOL FORCING

Numerical simulation of physical processes





Isomorphism of processes to computer code

Modeling aerosol processes requires understanding these processes, developing and testing their numerical representations, and incorporating these representations in global scale models.

SEVEN DIMENSIONS OF AEROSOL FORCINGS

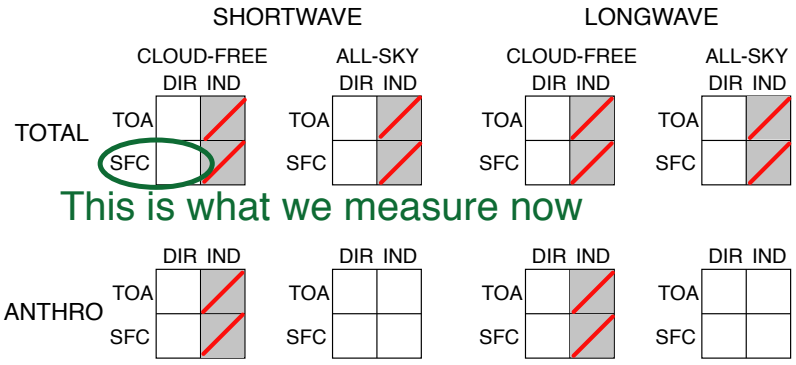
Denotes that indicated forcing is not defined.

80 Distinct aerosol forcings

SEVEN DIMENSIONS OF AEROSOL FORCINGS

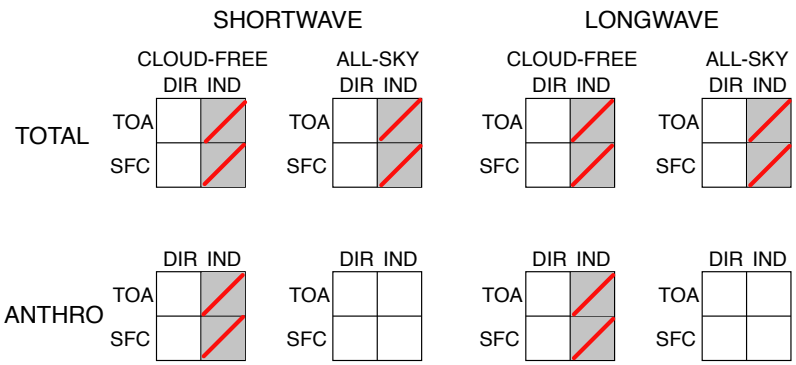
LOCAL

INSTANTANEOUS



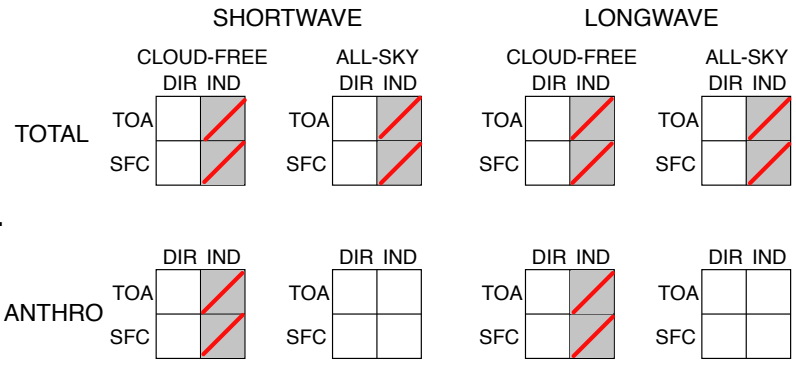
This is what we measure now

24-HOR TO ANNUAL AVG



GLOBAL

INSTANTANEOUS



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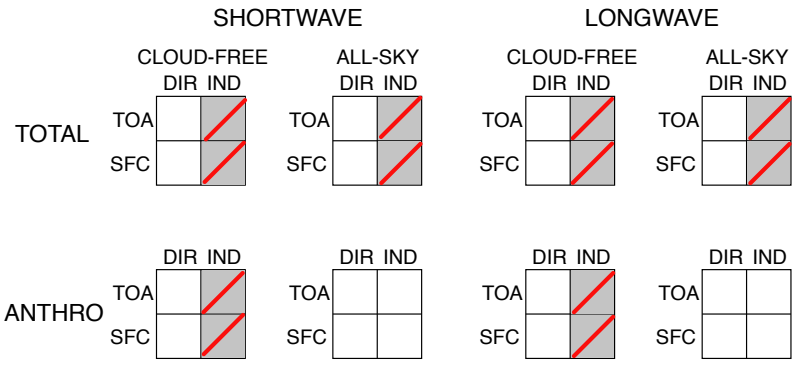

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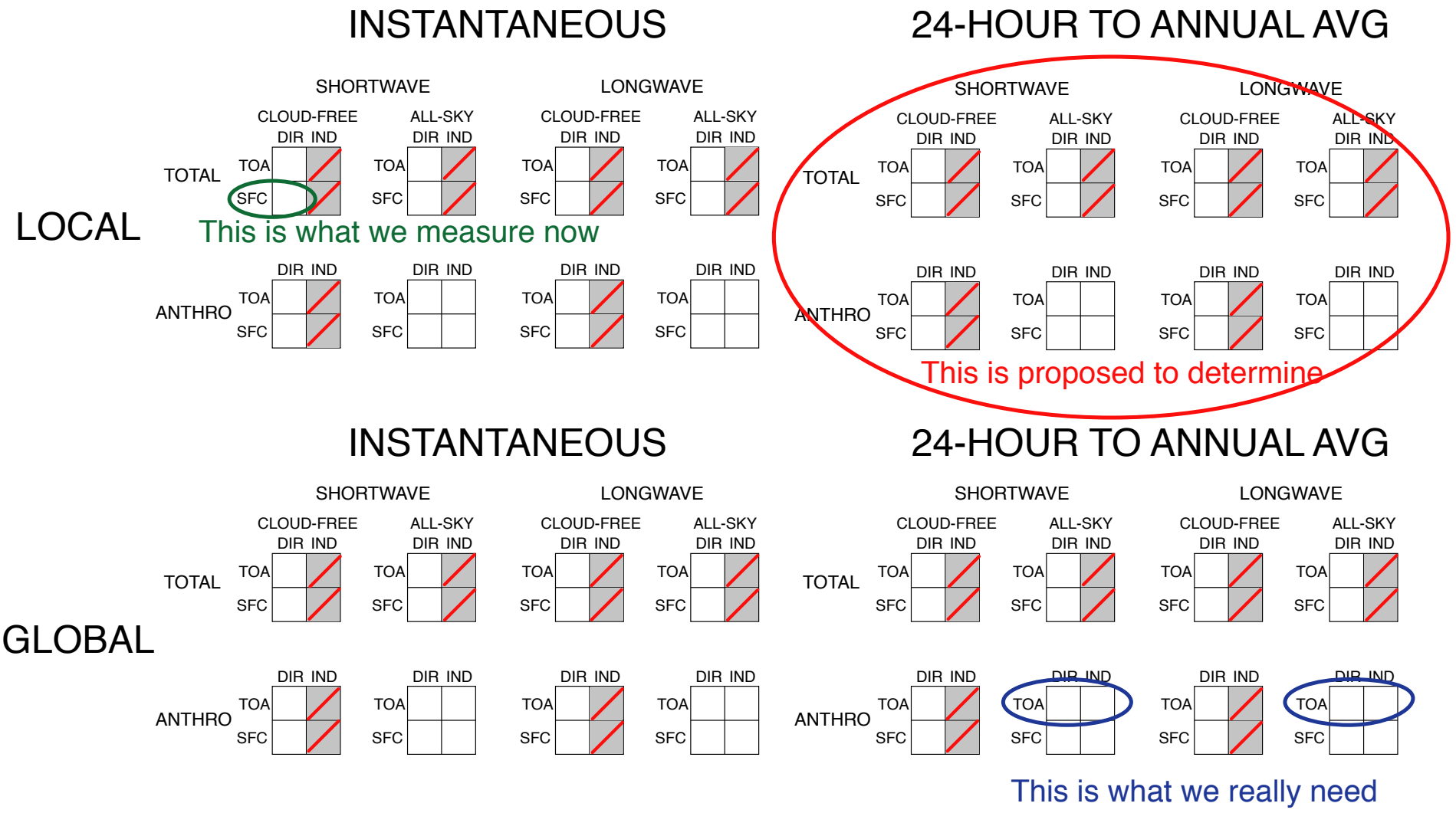
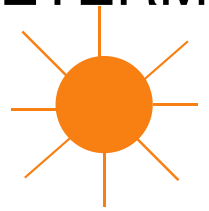
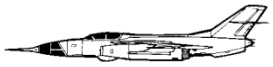


80 Distinct aerosol forcings

DIRECT DETERMINATION OF AEROSOL FORCINGS AT ARM SITES



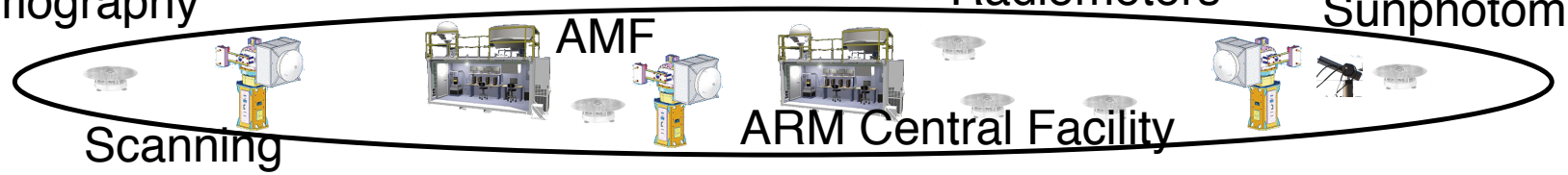
Measurements 24-7-365



Drone
Net SW and LW at TOA

3-D Characterization of Aerosol and Cloud Properties

Characterization of 3-D Cloud Properties by Radars, Tomography



CONCLUSIONS

- The present uncertainty in climate sensitivity means that the amount of CO_2 that can be added to the atmosphere consistent with a given increase in global temperature is ***uncertain even in sign***.
- Ability to project future climate change for a given change in atmospheric composition must be greatly improved.
- Confidence in such projections is limited by uncertainty in

  Climate forcing

  Climate sensitivity
- ASR is well positioned to make advances on both fronts.

RECOMMENDATIONS

- ASR needs to make major efforts on both fronts:

  Climate sensitivity, through frequent, systematic evaluations of model performance in the fast physics.

  Climate forcing, through improved understanding and model-based representation of aerosol processes, ***and*** through measurement-based determination of aerosol forcings.

- To achieve this ***ASR must be managed as a mission driven program!***

- To make the needed advances ASR requires a ***major increase in resources***.